APPLICATION NO. 09/826,117

INVENTOR: Urbain A. von der Embse

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Hybrid Walsh Codes for CDMA

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BACKGROUND OF THE INVENTION

I. Field of the Invention

The present invention relates to CDMA (Code Division Multiple Access) cellular telephone and wireless data communications with data rates up to multiple T1 (1.544 Mbps) and higher (>100 Mbps), and to optical CDMA with data rates in the Gbps and higher ranges. Applications are mobile, point-to-point and satellite communication networks. More specifically the present invention relates to novel hybrid complex Walsh codes developed to replace current real Walsh orthogonal CDMA channelization codes.

II. Description of the Related Art

CDMA art is represented by the recent work on multiple access for broadband wireless communications which includes "Multiple Access for Broadband Networks", IEEE Communications magazine July 2000 Vol. 38 No. 7, "Third Generation Mobile Systems in Europe", IEEE Personal Communications April 1998 Vol. 5 No. 2 ,IS-95/IS-95A, the IS-95/IS-95A, the 3G CDMA2000 and W-CDMA, and the listed patents.

FIG. **1** is a representative wireless cellular communication network application of the CDMA trasmitter in FIG. **2**. FIG. **1** is a schematic layout of part of a CDMA network which depicts cells **101,102,103,104** that partition this portion of the area coverage of the network, depicts one of the users **105** located within a cell with forward and reverse communications links **106** with the cell-site base station **107**, depicts the base station communication links **108** with the MSC/WSC **109**, and depicts the MSC/WSC communication links with another base station **117**, with another MSC/WSC **116**, and with external elements **110,111,112,113,114,115**. One or more base stations are assigned to each cell or multiple cells or sectors of cells depending on the application. One of the base stations **109** in the network serves as the MSC (mobile switching center) or WSC (wireless switching center) which is the network system controller and switching and routing center that controls all of user timing, synchronization, and traffic in the network and with all external interfaces including other MSC's. External interfaces could include satellite **110**, PSTN (public switched telephone network) **111**, LAN (local area network) **112**, PAN (personal area network) **113**, UWB (ultra-wideband network) **114**, and optical networks **115**. As illustrated in the figure, base station **107** is the nominal cell-site station for cells i-2, i-1, i, i+1 identified as **101,102,102,104**, which means it is intended to service these cells with overlapping coverage from other base stations. The cell topology and coverage depicted in the figure are intended to be illustrative.

Fig. **2** depicts a representative embodiment of the CDMA transmitter signal processing in FIG. **1** for the forward and reverse CDMA links **106** between the base station and the users for CDMA2000 and W-CDMA that implements the CDMA coding for synchronization, real Walsh channelization, and scrambling of the data for transmission. CDMA2000 and W-CDMA use real Walsh codes **120** for channelization of the data. which can be expressed in

layered format which progresses from the highest data rate for the shortest codes to the lowest data rate for the longest codes in a format referred to as OVSF (orthogonal fixed spreading factor) codes. OVSF implementation of real Walsh codes **120** supports a variable data rate with variable length real Walsh codes over a fixed transmission channel. This invention disclosure will use fixed length codes which implement OVSF by assigning more code vectors to the higher data rate users. Data inputs **112** in FIG. **1A** to the transmitter CDMA signal processing are the inphase data symbols $R(u_R)$ **118** and quadrature data symbols $I(u_I)$ **119** of the complex data symbols $Z(u)=R(u_R)+j\ I(u_I)$ from the block interleaving processing in the transmitter. A real Walsh code **120** ranging in length from N=4 to N=512 chips spreads and channelizes the data by encoding **121** the inphase and quadrature data symbols with rate R=N codes corresponding to the channel assignments of the data chips. A long PN code **122** encodes the inphase and quadrature real Walsh encoded chips **123** with a 0,1 binary code. Encoding is a (+/-) sign change to the chip symbols corresponding to the 0,1 code value. Long code characteristics have the PN property with quasi-orthogonal auto-correlations and cross-correlations. This long PN code covering of the real Walsh encoded chips is followed by a short complex PN code covering in **124,125,126**. This complex PN short code encodes the inphase and quadrature chips with a complex multiply operation **126**. Outputs are inphase and quadrature components of the complex chips which have been rate R=1 phase coded with both the long and short PN codes. Low pass filtering (LPF), summation (Σ) over the Walsh channels for each chip symbol, modulation of the chip symbols to generate a digital waveform, and digital-to-analog (D/A) conversion operations **127** are performed on these encoded inphase and quadrature chip symbols to generate the analog inphase $x(t)$ signal **128** and the quadrature $y(t)$ signal **129** which are the components of the complex signal $z(t)=x(t)+jy(t)$ where $j=\sqrt{-1}$. This complex signal $z(t)$ is single-sideband up-

converted to an IF frequency and then up-converted by the RF frequency front end to the RF signal v(t) **133**. Single sideband up-conversion of the baseband signal is performed by multiplication of the inphase signal x(t) with the cosine of the carrier frequency f_0 **130** and the quadrature signal y(t) by the sine of the carrier frequency **131** which is a 90 degree phase shifted version of the carrier frequency, and summing **132** to generate the real signal v(t) **133**.

SUMMARY OF THE INVENTION

This invention is a new approach to the application of Walsh orthogonal codes for CDMA, which offers to replaces the current real Walsh codes with complex Walsh codes called hybrid Walsh codes and with generalized complex Walsh codes called generalized hybrid Walsh codeswhich allow greater flexibility in the selection of the code lengths and enable other codes to be combined with the hybrid Walsh. A useful property is that an application capable of using the complex Walsh codes can simply turn-off the complex axis components of the complex Walsh codes for real Walsh CDMA coding and decoding. Hybrid Walsh codes are the closest possible approximation to the DFT with orthogonal code vectors taking the values {1+j, -1+j, -1-j, 1-j} or equivalently the values {1, j, -1, -j} and are constructed with reordering permutations of the real Walsh. Generalized hybrid Walsh codes are constructed by combining other codes using tensor product construction, direct sum construction, and functional combining.

BRIEF DESCRIPTION OF THE DRAWINGS AND THE PERFORMANCE DATA

The above-mentioned and other features, objects, design algorithms, implementations, and performance advantages of the present invention will become more apparent from the detailed description set forth below when taken in conjunction with the drawings and performance data wherein like reference characters and numerals denote like elements, and in which:

FIG. **1** depicts a represenative CDMA cellular network with the communications link between a base station and a user.

FIG. **2** depicts the CDMA transmit signal processing.

FIG. **3** depicts the receive CDMA signal processing.

FIG. **5** defines the implementation algorithm generating hybrid Walsh codes from real Walsh codes.

FIG. **6** depicts the hybrid Walsh transmit signal processing.

FIG. **7** depicts the hybrid Walsh receive signal processing.

DISCLOSURE OF THE INVENTION

The new complex Walsh orthogonal CDMA codes which are the hybrid Walsh codes in this invention disclosure are derived from the current real Walsh codes by starting with the correspondence of the current real Walsh codes with the discrete Fourier transform (DFT) basis vectors. The real orthogonal Hadamard and Walsh, codes in the N-dimensional real code space R^N and the complex orthogonal DFT codes in the N-dimensional complex code space C^N are defined in equations **(3)**. defined in equation **(3)** in which N=2^M with M an integer. Hadamard codes in their reordered form known as Walsh codes are used in the current CDMA, in the G3 CDMA, and in the proposals for all future CDMA. Walsh codes reorder the Hadamard codes according to increasing sequencywhich is the average rate of change of the sign of the codes. In these equations the even and odd property of the code vectors is in reference to the midpoint of the vectors similar to the concept of even and odd frequencies.

Orthogonal CDMA codes **(3)**

37 Hadamard codes

H = Hadamard NxN orthogonal code matrix with N rows of N chip code vectors
= [H(u)] matrix of row vectors H(u)
= [H(u,n)] matrix of elements H(u,n)

H(u) = Hadamard code vector u
= [H(u,0), H(u,1), …, H(u,N-1)]
= 1xN row vector of chips H(u,0),….,H(u,N-1)

H(u,n) = Hadamard code u chip n

$= +/+1$ possible values

$= (-1)\,\hat{}\,[\sum_{i=0}^{i=M-1} u_i n_i\ ]$

where $u = \sum_{i=0}^{i=M-1} u_i\, 2^i$ binary representation of u

$n = \sum_{i=0}^{i=M-1} n_i\, 2^i$ binary representation of n

38 Walsh codes

W = Walsh NxN orthogonal code matrix consisting of N rows of N chip code vectors

= [W(u)] matrix of row vectors W(u)

= [W(u,n)] matrix of elements W(u,n)

W(u) =Walsh code vector u

= [W(u,0), W(u,1), …, W(u,N-1)]

$W_e(u)$ = Even Walsh code vector

= W(2u) for u=0,1,…,N/2-1

$W_o(u)$ = Odd Walsh code vectors

= W(2u-1) for u=1,…,N/2

W(u,n) = Walsh code u chip n

$= +/+1$ possible values

$= (-1)\,\hat{}\,[u_{M-1} n_0 + \sum_{i=1}^{i=M-1} (u_{M-1-i} + u_{M-i}) n_i\ ]$

39 DFT codes

E = DFT NxN orthogonal code matrix consisting of N rows of N chip code vectors

= [E(u)] matrix of row vectors E(u)

= [E(u,n)] matrix of elements E(u,n)

E(u) = DFT code vector u

= [E(u,0), E(u,1), …, E(u,N-1)]

= 1xN row vector of chips E(u,0),….,E(u,N-1)

= C(u) + j S(u) for u=0,1,…,N-1

C(u) = Even code vectors for u=0,1,…,N-1

$= [1, \cos(2\pi\ u\ 1/N), \ldots, \cos(2\pi\ u\ (N-1)/N)]$

$S(u)$ = Odd code vectors for $u=0,1,\ldots,N-1$

$= [0, \sin(2\pi\ u\ 1/N), \ldots, \sin(2\pi\ u\ (N-1)/N)]$

$E(u,n)$ = DFT code u chip n

$= \exp\hat{}j2\pi\ un/N$

$= \cos(2\pi\ un/N) + j\sin(2\pi\ un/N)$

= N possible values on the unit circle

FIG. **5A** defines the reordering permutation algorithm which constructs the real code vector $W_R(u)$ and the imaginary code vector $W_I(u)$ of the hybrid Walsh code vector $\underline{W}(u) = W_R(u)+j\ W_I(u)$ from the real Walsh code vectors $W(u)$. Code index u in **167** is the sequency index since the codes are arranged in lexicographic order with code index u equal to the sequency value for the code. This ordering of the hybrid WaLsh is identical to the frequency ordering of the DFT which establishes the correspondence "sequency~frequency" meaning that the code index u=0,1,2,… is the sequency index for hybrid Walsh codes and is the frequency index for the DFT codes. Lexiographic in the context of the hybrid Walsh refers to the reordering with increasing sequency. The reordering in FIG. **5A** is a permutation or equivalent a reordering transformation of the real Walsh mapping onto the real and imaginary componenents of the hybrid Walsh in **168** and **169** respectively.

FIG. **5B** maps the algorithm in FIG. **5A** into an algorithm that constructs the real code vector $W_R(u)$ and the imaginary code vector $W_I(u)$ of the hybrid Walsh code vector $\underline{W}(u) = W_R(u)+j\ W_I(u)$ from the even and odd Walsh code vectors $W_e(u)$ and $W_o(u)$ defined in equations **(3)**. The lexicographic reordering algorithm for the real axis code vectors **171** and the imaginary axis code vectors **172** is defined for the code or sequency index u in **170**.

Sequency~frequency and even and odd correspondences are defined in equations **(6)** where the correspondence operator "~" represents the even and odd correspondence between the Walsh and DFT codes, and additionally represents the sequency~frequency correspondence.

Hybrid Walsh ~ DFT correspondence **(6)**

for $u = 0$

$$E(0) = C(0) \sim \underline{W}(0) = W_e(0)$$

for $u = 1,2,...,N/2-1$

$$\begin{aligned} E(u) = C(u)+jS(u) \sim \underline{W}(u) &= W(2u) + jW(2u-1) \\ &= W_e(u) + jW_o(u) \end{aligned}$$

for $u = N/2$

$$\begin{aligned} E(N/2) = C(N/2) \sim \underline{W}(N/2) &= W_o(N/2)+jW_o(N/2) \\ &= W(N-1)+jW(N-1) \end{aligned}$$

for $u = N/2+\Delta u$ with $\Delta u = 1,2,...,N/2-1$

$$\begin{aligned} E(u) &= C(N/2-\Delta u)-jS(N/2-\Delta u) \\ \sim \underline{W}(u) &= W(N-1-\Delta_e i)+jW(N-1-\Delta_o u) \\ &= W_o(N/2-\Delta u)+jW_e(N/2-\Delta u) \end{aligned}$$

In these equations the indexing for the even real Walsh vectors is $\Delta_e u=2\Delta u$ and the indexing for the odd real Walsh vectors is $\Delta_o u=2\Delta u-1$. This equation defines the lexicographic reordering algorithms and demonstrates their uniqueness.

The hybrid Walsh code matrix $\underline{W}$ derived from the algorithms in FIG. **5A,5B** is given in equations **(7)** for N=8 and has code

rescaling by $1/\sqrt{2}$ which is implemented by the multiplicative constant $(1/\sqrt{2})\exp(-j\pi/4) = (1-j)/2$ the $\underline{W}*(1-j)/2$ hybrid Walsh matrix has code values $\{1, j, -1, -j\}$ on the unit circle in the complex plane with code values along the real and imaginary axes as shown in equations **(7)** and wherein "*" indicates multiplication.

$$\underline{W} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 \\ 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 \\ 1 & -1 & 1 & -1 & -1 & 1 & -1 & 1 \\ 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \\ 1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 \\ 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 \\ 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 \end{bmatrix} + j \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 \\ 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 \\ 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \\ 1 & -1 & 1 & -1 & -1 & 1 & -1 & 1 \\ 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 \\ 1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 \end{bmatrix} \quad \textbf{(7)}$$

$$\underline{W}*(1-j)/2 = [\ \underline{W}\ (u, n)\ *(1-j)/2\ ]$$

$$= \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & j & j & -1 & -1 & -j & -j \\ 1 & j & -1 & -j & 1 & j & -1 & -j \\ 1 & -1 & -j & j & -1 & 1 & j & -j \\ 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \\ 1 & -1 & j & -j & -1 & 1 & -j & j \\ 1 & -j & -1 & j & 1 & -j & -1 & j \\ 1 & 1 & -j & -j & -1 & -1 & j & j \end{bmatrix}$$

FIG. **6** describes the CDMA transmit signal processing for the cellular network in FIG. **1** using the hybrid Walsh complex channelization codes in place of the real Walsh codes. FIG. **6** depicts a representative embodiment of the transmitter signal processing for the forward and reverse CDMA links **106** in FIG. **1** between the base station and the user for CDMA2000 and W-CDMA. Similar to FIG. **2** the data inputs are the inphase data symbols R **173** and quadrature data symbols I **174**. Inphase **175** hybrid Walsh codes $\underline{W}_R$ are generated in **168** in Fig. **5A** and in **171** in FIG. **5B**. Quadrature **176** hybrid Walsh codes $\underline{W}_I$ are implemented in **169** in FIG. **5A** and in **172** in FIG. **5B**. A complex multiply **177** encodes the data symbols with the hybrid Walsh $\underline{W}$ codes in the encoder using the inphase (real) $\underline{W}_R$ and quadrature (imaginary) $\underline{W}_I$ code components of $\underline{W}=\underline{W}_R+j\underline{W}_I$ to generate a rate R=N set of hybrid Walsh encoded data chips for each inphase and quadrature data symbol. Following the hybrid Walsh encoding the transmit signal processing in **178-to-189** is identical to the corresponding transmit signal processing in **122-to-133** in FIG. **2**.

FIG. **6** depicts an embodiment of the upgrade to the current CDMA transmitter art using the hybrid Walsh codes in place of the real Walsh codes and with current art signal processing changes

this figure is representative of the use of hybrid Walsh codes in place of the real Walsh codes for other current art CDMA receiver embodiments of this invention disclosure. Other embodiments of the CDMA transmitter include changes in the ordering of the signal processing, single channel versus multi-channel hybrid Walsh encoding, summation or combining of the hybrid Walsh channels by summation over like chip symbols, analog versus digital signal representation, baseband versus intermediate frequency IF CDMA processing, the order and placement in the signal processing thread of the Σ, LPF, and D/A signal processing operations, and the up-conversion processing. The order of the rate R=1 PN code multiplies in FIG. **6** can be changed since the covering operations implemented by the multiplies are linear in phase, which means the short code complex multiply **180,181,182** in FIG. **6** can occur prior to the long code multiply **178,179** and moreover the long code can be complex with the real multiply **179** replaced by the equivalent complex multiply **182**.

FIG. **7** is the upgrade to the cellular network receive CDMA decoding in FIG. **1** using the hybrid Walsh complex channelization codes in place of the real Walsh codes. FIG. **7** depicts a representative embodiment of the receiver signal processing for the forward and reverse CDMA links **106** in FIG. **1** between the base station and the user for CDMA2000 and W-CDMA that implements the CDMA decoding for the decovering by the long code and the short complex codes followed by the hybrid Walsh decoding to recover estimates of the transmitted inphase (real) data symbols R **173** and quadrature (imaginary) data symbols I **174** in FIG. **6**. Depicted are the principal signal processing that is relevant to this invention disclosure. Similar to FIG. **3** the signal input $\hat{v}(t)$ **190** is the received estimate of the transmitted CDMA signal $v(t)$ **189** in FIG. **6**. The receive signal recovery in **191-to-201** is identical to the corresponding receive signal processing in **135-**

to-145 in FIG. **3.** The decovered chip symbols are rate R=1/N decoded by the hybrid Walsh complex decoder **204** using the complex conjugate of the hybrid Walsh code structured as the inphase hybrid Walsh code $\underline{W}_R$ **202** and the negative of the quadrature hybrid Walsh code $(-)\underline{W}_I$ **203** to implement the complex conjugate of the hybrid Walsh code in the complex multiply and decoding operations. Decoded output symbols are the inphase data symbol estimates $\hat{R}$ **205** and the quadrature data symbols $\hat{I}$ **206.**

FIG. **7** depicts an embodiment of the upgrade to the current CDMA receiver art using the hybrid Walsh code in place of the real Walsh code and with current art signal processing changes this figure is representative of the use of hybrid Walsh codes in place of the real Walsh codes for other current art CDMA receiver embodiments of this invention disclosure. Other embodiments of the CDMA receiver include changes in the ordering of the signal processing, analog versus digital signal representation, down-conversion processing, baseband versus IF frequenncy CDMA processing, the order and placement in the signal processing thread of the Σ, LPF, and A/D signal processing operations, and single channel versus multi-channel hybrid Walsh decoding, The order of the rate R=1 PN code multiplies in FIG. **7** which perform the code decovering can be changed since the covering operations implemented by the multiplies are linear in phase, which means the short code complex multiply **197,198,199** can occur after to the long code multiply **200,201** and moreover the long code can be complex with the real multiply **201** replaced by the equivalent complex multiply **199.**

Although not considered in these examples , it is possible to use combinations of both complex and real data symbols similar to the approach for real Walsh CDMA since the complex Walsh code vectors are the reordered real Walsh code vectors along the real

axis and a distinct reordering of the real Walsh code vectors along the imaginary axis.

It should be obvious to anyone skilled in the communications art that these example implementations in FIG. 6, **7** clearly define the fundamental CDMA signal processing relevant to this invention disclosure and it is obvious that this example is representative of the other possible signal processing approaches.

For cellular applications the transmitter description describes the transmission signal processing applicable to this invention for both the hub and user terminals, and the receiver describes the corresponding receiving signal processing for the hub and user terminals for applicability to this invention.

Generalized hybrid Walsh codes allow the code length N to be a product of powers of primes **60** in equations **(17)** or a sum of powers of primes **61** in equations **(17)**, at the implementation cost of introducing multiply operations into the CDMA encoding and decoding. In the previous disclosure of this invention the N was assumed to be equal to a power of 2 which means N=2^M corresponding to prime p_0 = 2 and the integer $M=m_0$. This restriction was made for convenience in explaining the construction of the hybrid Walsh and is not required since it is well known that Hadamard matrices exist for non-integer powers of 2 and, therefore, hybrid Walsh matrices exist for non-integer powers of 2.

Length N of generalized hybrid Walsh codes **(17)**

60 Tensor product code construction

$$N = \prod_{k} p_k\text{^}m_k$$

$$= \prod_{k} N_k$$

where

p_k = prime number indexed by k starting with k=0

m_k = order of the prime number p_k

N_k = Length of code for the prime p_k

= $p_k\text{^}m_k$

61 Direct sum code construction

$$N = \sum_{k} p_k\text{^}m_k$$

$$= \sum_{k} N_k$$

Add-only arithmetic operations are required for encoding and decoding both real Walsh and hybrid Walsh CDMA codes since the real Walsh values are +/-1 and the hybrid Walsh values are {+/-1 +/-j} or equivalently are {1,j,-1,-j} under a -90 degree rotation and normalization which means the only operations are sign transfer and adds plus subtracts which are add-only algebraic operations. Multiply operations are more complex to implement than add operations. However, the advantages of having greater flexibility in choosing the orthogonal CDMA code lengths N using equations **(17)** can offset the expense of multiply operations for particular applications. Additioonally, the generalized hybrid Walsh codes be constructed to have designer coordinates and properties. Accordingly, this invention includes the concept of generalized hybrid Walsh orthogonal CDMA codes with the flexibility to meet these needs. This extended class of hybrid Walsh codes supplements the hybrid Walsh codes by combining with Hadamard (or real Walsh), DFT, and

other orthogonal codes as well as with quasi-orthogonal PN by relaxing the orthogonality property to quasi-orthogonality.

Generalized hybrid Walsh orthogonal CDMA codes can be constructed as demonstrated in **64** and **65** in equations **(18)** for the tensor product, in **66** for the direct sum, and in **67** for functional combining. The example code matrices considered for orthogonal CDMA codes in **62** for the construction of the generalized hybrid Walsh are the DFT E and Hadamard H or equivalently Walsh W, in addition to the hybrid Walsh $\underline{W}$. The algorithms and examples for the construction start with the definitions **63** of the NxN orthogonal code matrices $\underline{W}=\underline{W}_N$, $E=E_N$, $H=H_N$ for N=2,4. and the equivalence of E_4 and W_4 after the $\underline{W}_4$ is rotated through the angle -45 degrees and rescaled. The CDMA current and developing standards use the prime 2 which generates a code length $N=2^M$ where M=integer. For applications requiring greater flexibility in code length N, additional primes can be used using the tensor construction. This flexibility is illustrated in **65** with the addition of prime=3. The use of prime=3 in addition to the prime=2 in the range of N=8 to N=64 is observed to increase the number of N choices at a modest cost penality of using multiples of the angle increment 30 degrees for prime=3 in addition to the angle increment 90 degrees for prime=2. As noted in **65** there are several choices in the ordering of the tensor product construction and 2 of these choices are used in the construction. In general, different orderings of the tensor product yield different sets of orthogonal codes.

Direct sum construction provides greater flexibility in the choice of N without necessarily introducing a multiply penality. However, the addition of the zero matrix in the construction is generally not desirable for CDMA communications. A functional combining in **67** in equation **(18)** removes these zero matrices at

the cost of relaxing the orthogonality property to quasi-orthogonality.

Deneralized hybrid Walsh orthogonal codes **(18)**

62 Code matrices for orthogonal codes

$\underline{W}$ = NxN hybrid Walsh $\underline{W}$

E_N = NxN DFT E

H_N = NxN Hadamard H

63 Low-order code definitions and equivalences

$$2x2 \quad H_2 = \begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$$

$$= E_2$$

$$= (e^{-j\pi/4}/\sqrt{2})*\underline{W}_2$$

$$3x3 \quad E_3 = \begin{bmatrix} 1 & 1 & 1 \\ 1 & e^{j2\pi/3} & e^{j2\pi 2/3} \\ 1 & e^{j2\pi 2/3} & e^{j2\pi/3} \end{bmatrix}$$

$$4x4 \quad H_4 = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 \end{bmatrix}$$

$$\underline{W}_4 = \begin{bmatrix} 1+j & 1+j & 1+j & 1+j \\ 1+j & -1+j & -1-j & 1-j \\ 1+j & -1-j & 1+j & -1-j \\ 1+j & 1-j & -1-j & -1+j \end{bmatrix}$$

$$E_4 = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & j & -1 & -j \\ 1 & -1 & 1 & -1 \\ 1 & -j & -1 & j \end{bmatrix}$$

$$= (e^{-j\pi/4}/\sqrt{2})W_4$$

64 Tensor product construction for $N=\prod_k N_k$

C_N = NxN generalized hybrid Walsh code natrux

$= C_0 \prod_{k>0} \otimes \mathbf{C}_{N_k}$

where the tensor product "⊗" is defined as:

$A \otimes B$ = tensor product of matrix A and matrix B

= NxN matrix of elements [a_{ik} B]

where $A = N_a x N_a$ orthogonal code matrix $[a_{ik}]$

$B = N_b x N_b$ orthogonal code matrix

$N = N_a N_b$

65 Generalized hybrid Walsh code matrix Tensor product construction examples for primes p=2,3 and the range of sizes $8 \le N \le 64$

8x8 $C_8 = \underline{W}_8$

12x12 $C_{12} = \underline{W}_4 \otimes \mathbf{E}_3$

$C_{12} = \mathbf{E}_3 \otimes \underline{W}_4$

16x16 $C_{16} = \underline{W}_{16}$

18x18 $C_{18} = \underline{W}_2 \otimes \mathbf{E}_3 \otimes \mathbf{E}_3$

$C_{18} = \mathbf{E}_3 \otimes \mathbf{E}_3 \otimes \underline{W}_2$

24x24 $C_{24} = \underline{W}_8 \otimes \mathbf{E}_3$

$C_{24} = \mathbf{E}_3 \otimes \underline{W}_8$

32x32 $C_{32} = \underline{W}_{32}$

36x36 $C_{36} = \underline{W}_4 \otimes \mathbf{E}_3 \otimes \mathbf{E}_3$

$C_{36} = \mathbf{E}_3 \otimes \mathbf{E}_3 \otimes \underline{W}_4$

48x48 $C_{48} = \underline{W}_{16} \otimes \mathbf{E}_3$

$C_{48} = \mathbf{E}_3 \otimes \underline{W}_{16}$

64x64 $C_{64} = \underline{W}_{64}$

66 Generalized Hyhbrid Walsh code matrices usingdirect sum construction for $N = \sum_k N_k$

C_N = NxN generalized hybrid Walsh

$$C_N = C_0 \cdot \prod_{k>0} \oplus C_{N_k}$$

where the direct sum definition is:

A = $N_a x N_a$ orthogonal code matrix

B = $N_b x N_b$orthogonal code matrix

$A \oplus B$ = Direct sum of matrix A and matrix B

= $N_a + N_b$ x $N_a + N_b$ orthogonal code matrix

$$= \left[\begin{array}{c:c} A & O_{N_a x N_b} \\ \hdashline O_{N_b x N_a} & B \end{array}\right]$$

where $O_{N_1 x N_2}$ = $N_1 x N_2$ zero matrix

67 Generalized Hyhbrid Walsh code matrices using functional combining with direct sum construction for $N = \sum_k N_k$

C_N = NxN generalized hybrid Walsh code matrix

C_N = $f(\; C_0 \prod_{k>0} \oplus C_{N_k} \;,\; C_P\;)$

where

f(A,B) = functional combining operator of A,B
= the element-by-element covering of A with B for the elements of A ≠ 0,
= the element-by-element sum of A and B for the elements of A = 0

C_P = NxN pseudo-orthogonal complex code matrix whose row code vectors are independent strips of PN codes for the real and imaginary components

It should be obvious to anyone skilled in the communications art that this example implementations of the generalized hybrid Walsh in equations **(18)** clearly define the fundamental CDMA signal processing relevant to this invention disclosure and it is obvious that this example is representative of the other possible signal processing approaches. For example, the tensor product matrices E_N and H_N can be replaced by functionals.

For cellular applications the transmitter description which includes equations **(18)** describes the transmission signal processing applicable to this invention for both the hub and user

terminals in FIG. **1**, and the receiver corresponding to the decoding of equations **(18)** describes the corresponding receiving signal processing for the hub and user terminals in FIG. **1** for applicability to this invention.

It is well known that fast and efficient encoding and decoding algorithms exist for the real Walsh CDMA codes. It is obvious that with suitable modifications these algorithms can be used to develop fast and efficient encoding and decoding algorithms for the hybrid Walsh CDMA codes since these complex codes have real and imaginary code vectors which are from the same set of real Walsh CDMA codes.

It is well known that the tensor product construction involving DFT, H and real Walsh orthogonal code vectors have efficient encoding and decoding algorithms. It is obvious that with suitable modifications these algorithms can be used to develop fast and efficient encoding and decoding algorithms for the tensor products of DFT, H and hybrid Walsh CDMA codes since these hybrid Walsh codes have real and imaginary code vectors which are from the same set of real Walsh CDMA codes. It is obvious that fast and efficient encoding and decoding algorithms exist for direct sum construction and functional combining.

Preferred embodiments in the previous description is provided to enable any person skilled in the art to make or use the present invention. The various modifications to these embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments without the use of the inventive faculty. Thus, the present invention is not intended to be limited to the embodiments shown herein but is to be accorded the wider scope consistent with the principles and novel features disclosed herein.

APPLICATION NO. 09/826,117

TITLE OF INVENTION: Hyhrid Walsh Codes for CDMA

INVENTOR: Urbain A. von der Embse

Currently amended DRAWINGS AND PERFORMANCE DATA

The original drawings filed in 2001 are currently amended with with the markup in the top margin "deleted sheets" for the original drawings being deleted and the markup in the top margin "replacement sheets" for their replacements. FIG. 4 is the only deleted original drawing which does not have a replacement.